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LCA OF BOOKS

Books from an environmental perspective—Part 2: e-books as an alternative to paper books

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Abstract
Purpose Information and communication technology (ICT) has been proposed as a means to facilitate environmental sustainability. Dematerialisation is one potential way of doing this. For books, this could be realized through using e-book readers, which share many of the qualities of printed media and have notably low-energy requirements during use. The main aim of this study was to analyse the environmental impacts of an e-book read on an e-book reader, and to identify key issues determining the magnitude of the impact. A second aim was to compare the e-book product system with a paper book product system using a life cycle perspective.
Materials and methods A screening LCA was performed on an e-book produced and read in Sweden. The e-book reader was assumed to be produced in China. The data used were general data from Ecoinvent 2.0 and site-specific data from companies participating in the study, whenever average data were not available.
Results and discussion The results showed that production of the e-book reader was the life cycle step contributing most to the environmental impact of the system studied, although data on the e-ink screen were lacking. The disposal phase leads to avoided impact as materials are recycled; however, these results are less certain due to limited data availability. When the e-book was compared with a paper book, the results indicated that the number of books read on the e-book reader during its lifetime was crucial when evaluating its environmental performance compared with paper books. The results indicate that there are impact categories and circumstances where paper books are preferable to e-books from an environmental perspective and vice versa.
Conclusions There is no single answer as to which book is better from an environmental perspective according to the results of the current study. To improve the e-book environmental performance, an e-book reader should be used frequently, the life time of the device should be prolonged, as far as possible, and when not in use anymore, the device should be disposed of in a proper way, making material recycling possible. In addition, the production of the e-reader should be energy efficient and striving towards minimisation of toxic and rare substances.

Keywords Book · e-book · e-paper · e-book reader · Internet · Printed media

1 Preamble

Developments in information and communication technology (ICT) are providing new solutions in different fields of society. The conditions for the media sector are changing and ICT is part of the reason for this. Traditional ways of providing and consuming media content are being complemented or challenged by electronic alternatives. This study examined the potential environmental impact of books, comparing traditional paper books sold in traditional bookshops, traditional paper books sold via internet bookshops and e-books sold via internet books stores and read on an e-book reader. The results of the screening LCA are presented in two papers, the first focusing on paper books from traditional and internet bookshops and the second on the e-book compared with the paper book.

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2 Introduction

Different strategies have been suggested to decrease the environmental impact of society and to enable environmental sustainability. Information and communication technology (ICT) is considered a possible mean, but its potential has been debated and rebound effects highlighted. Hilty et al. (2006) identified possibilities for ICT to promote environmental sustainability including dematerialisation of products, intelligent heating and mobile work; the latter with the potential to both decrease and increase environmental impact. Berkhout and Hertin (2004) concluded that ICT can lead to positive or negative environmental impacts. Dematerialisation is one potential way of using ICT for environmental sustainability. Dematerialisation, shifting to virtual goods, was identified by Hilty et al. (2006) as important due to the high potential for change and the potential effect influencing several of the aspects they assessed, e.g. freight transport and waste and energy use in the industrial sector.

Several studies have considered printed media compared with electronic alternatives. Studies on newspapers have indicated a potential benefit from electronic versions (Hischier and Reichart 2001, 2003; Moberg et al. 2007, 2010; Toffel and Horvarth 2004), but also a negative effect (Kamburow 2004). Gard and Keoleian (2003) concluded that depending on the scenario assessed, different systems for printed or electronic scholarly journals were preferable. In other studies, the electronic version of documents such as invoices proved preferable (Moberg et al. 2008; Schmidt and Hedal Klöfverpris 2009). Studies on scholarly books have shown apparently conflicting results (Enroth, 2009; Kozak 2003). These two studies compared printed books with e-books read on e-book readers with LCD screens in the U.S. (Kozak 2003) or on computers in Norway (Enroth 2009). Another major difference between the two studies was that the former included personal transportation by car to buy the book, as well as the energy use of the bookshop. Both studies showed that the energy use during operation was a major constituent of the environmental impact of the electronic media, although in the Enroth (2009) study the impact of production of the equipment was greater.

Lately, the development of e-paper displays intended to share many of the qualities of paper, such as reading using reflective light, high resolution, 180° viewing angle and high contrast, has resulted in several products on the market. These e-reader devices (also called electronic papers, e-papers or e-book readers) are interesting from an environmental perspective due to their notably low-power consumption during use. The e-paper display differs from traditional display technologies, such as LCD, OLED, CRT or plasma screens (see e.g. Senarclens de Grancy 2008). Apart from the display itself, the e-paper device consists mostly of standard components, such as plastic housing, electronic components of different kinds and a rechargeable battery. In an earlier study on newspapers where a printed version was compared with an electronic version read on an e-book reader, the data on production and waste management of the electronic device were very limited (Moberg et al. 2007, 2010). In at least some of the other studies cited, the data on production and waste management of the electronic devices seem to be limited as well (e.g. Kamburow 2004; Kozak 2003; Toffel and Horvath 2004). Previous results indicate that the reading time is crucial when using a computer to read electronic content, as this is a major contributor to the energy use of the system (Hischier and Reichart 2001; Enroth 2009). However, with e-book readers using e-paper displays, the energy use for reading is significantly decreased, and thus, the reading time is no longer a main issue and production and waste management become more important. Studies of media products accessed using these platforms are therefore of interest. Moberg et al. (2007, 2010) concluded that there is potential for e-book readers to decrease the environmental impact of newspapers. However, as the production and in some cases the disposal of the e-book reader were the main contributors to the environmental impact of the newspaper read on an e-book reader in those studies, more detailed study of these is relevant. It is also of interest to study the environmental implications of e-book readers as compared to books, as this is a market where the product has been introduced in practice more widely.

The main aim of the present study was to determine the environmental impact of an e-book read on an e-book reader and identify key issues determining the magnitude of the impact. A second aim was to compare the e-book product system with a paper book, using a life cycle perspective. In addition, areas with a lack of data and major uncertainties were to be noted. More information on the scope of the study and the inventory data is given in Borggren and Moberg (2009) with appendices. The paper book used for comparison is described in a separate paper (Borggren et al. 2011).

3 Materials and methods

3.1 Method

Life Cycle Assessment (LCA) is described in textbooks (e.g. Baumann and Tillman 2004), scientific papers (e.g. Finnveden et al. 2009) and an ISO standard (ISO 2006). The present study comprises a screening LCA in the sense that easily accessible data were used. The study used the LCA software tool SimaPro 7.1.8 (PRé Consultants 2008)). As far as possible, data obtained from the Ecoinvent 2.0 database (Frischknecht et al. 2007a) as provided in SimaPro were used (PRé Consultants 2008). The intention was to study an e-book

in general, and general data were preferred. However, in several cases general data were not available and in these cases company- and site-specific data were used as approximations, as described below and in more detail in Borggren and Moberg (2009) with appendices. The data used were average (not marginal) data in line with an attributional LCA (Tillman 2000). For the impact assessment, CML impact assessment methods (Guinée et al. 2002), as provided in SimaPro 7.1.8, were used. Biotic carbon dioxide was excluded from the climate change impact assessment. The Cumulative Energy Demand (Frischknecht et al. 2007c), as implemented in SimaPro, was calculated.

3.2 Scope of the LCA

3.2.1 Description of the e-book and e-book reader studied

The average e-book defined for the study was intended to be equivalent to a 360-page hardcover novel, corresponding to the paper book assessed in a separate paper (Borggren et al. 2011). The paper book is a hypothetical average book assumed to be sold in average edition and each copy only read by one person. The e-book version of the book was a 1.5 MB PDF file downloaded using an average desktop computer. This e-book was assumed to be produced and bought in Sweden. The e-book reader was assumed to be produced in China and bought, used and disposed of in Sweden. At the time of this study (2009), the use of e-book readers was quite recent and assumptions had to be made. The functional unit of the book system studied was defined as ‘one specific book bought and read by one person’.

3.2.2 System studied

Editorial work The same editorial work as for the paper book was assumed (Borggren et al. 2011). Additional energy use for editing the electronic version was added, based on energy and heat use figures from the internet bookshop Adlibris and from Elib, a producer and distributor of downloadable and streaming audio books and e-books (P. Svärdson, Adlibris, personal communication, 2009). The total energy and heat used at the offices was allocated based on this specific book's share of total purchases.

Production of the e-book reader An e-book can be read on different kinds of electronic devices, such as a computer or a cell phone, but for this study, we assumed that the e-book was read on an e-book reader with an e-ink screen with properties similar to paper, as described in the introduction. To estimate the environmental impact of production of an e-book reader, a specific device was dismantled to identify the different components (see Appendix 1 in Borggren and Moberg 2009). These components were linked with the average data on production of electronic components available in Ecoinvent 2.0 (Hischier et al. 2007). These data were often western European or global average data rather than Chinese, but were used as estimates as Chinese data were not easily available. No information on the production of the e-ink screen was available.

Distribution of the e-book reader The e-book reader device was assumed to be transported from China to central Europe by boat for 15,000 km and then by lorry for an average distance of 500 km to possible retailers all over Sweden. The e-book reader was assumed to be bought at a traditional bookshop or over the internet and general data on personal transport from Ecoinvent 2.0 were used for the transportation related to the purchasing. The assumption for personal transport was that 2 km with a passenger car was allocated to the purchase of an e-book reader.

Electricity The electricity used was Swedish average electricity mix (Frischknecht et al. 2007b) for processes occurring in Sweden. For general processes from the Ecoinvent database, the electricity mix given in the data was used.

Internet use Buying an e-book from an internet bookshop was assumed to require a desktop computer and access to internet. The time spent on the website, including downloading the e-book, and the amount of data transferred were approximated to 8 min and 2.2 MB, respectively. The amount of data transferred included information on the website as well as the actual e-book down-loaded. Use of the internet was covered as energy use of the modem (approximated to 9 W), and the hubs, routers and switches of the internet infrastructure (Taylor and Koomey 2008). The rough figures provided by Taylor and Koomey (2008) illustrate 2006 conditions in the U.S. for the energy use of the hubs, routers and switches; these were halved to estimate the energy use per GB in 2008 (J. Malmodin, Ericsson Research, personal communication, 2009). Production of cables and carbon dioxide emissions related to construction work and dismantling were included (D. Lundén, TeliaSonera, personal communication, 2009). The operation and production of the desktop computer used were included. The impact of production was allocated based on the time of use (Borggren and Moberg 2009). The energy use for servers and data storage was accounted for in the editorial work as part of the energy use of Adlibris and Elib (P. Svärdson, Adlibris, personal communication, 2009).

E-book user Reading the e-book studied was assumed to require one charging of the battery (2.5 Wh). The battery needed charging about every 2–3 weeks. During the life of the e-book reader, 48 books of 360 pages (17,000 pages) were assumed to be read. The number of pages was chosen to facilitate comparison with the paper book and the number of

books was an assumption, which can be interpreted as, e.g. two books per month for 2 years or one book per month for 4 years. This assumption was varied in a sensitivity analysis.

Waste treatment of the e-book reader As for electronic waste in general, parts of the e-book reader entering the recycling system could be recycled. Based on information from S. Sjölin (personal communication, 2009) at the electronics recycling company Stena Technoworld and information about the e-book reader components, our assumptions regarding waste treatment were that 48 weight-% of the e-book reader was recycled, 29 weight-% incinerated with energy recovery and 23 weight-% sent to landfill. However, it is probable that not all e-book readers will reach the recycling system, so 75% of e-book readers were assumed to be handled as electronic waste. The devices not reaching the recycling system were not considered at all in the study, leading to underestimation of the environmental impact (positive and negative). The modelling of material recycling was based on data available in Ecoinvent 2.0 on recovery of materials and virgin production of the same material.

Paper book system The paper book system with which the e-book was compared is described in Borggren et al. (2011). The base scenario was a hardback novel with 360 pages produced in Sweden, printed on average European wood-free paper and sold in a traditional bookshop. Personal transportation of 2 km by passenger car was allocated to the paper book and each copy assumed to be read by one person only.

4 Results

4.1 Environmental impacts of an e-book read on an e-book reader

Figure 1 shows the relative contribution of the different life cycle phases of the e-book read on an e-book reader. Absolute values for the whole system are given in Table 1.

Table 1 Life cycle impacts of an e-book read on an e-book reader and a paper book (Borggren et al. 2011)

Impact category	Unit	E-book	Paper book, European wood-free paper
Energy	MJ eq	16	56
GWP	kg CO_2 eq	0.87	1.3
ADP	kg Sb eq	0.0058	0.0085
AP	kg SO_2 eq	0.023	0.0057
EP	kg PO_4 eq	0.0011	0.0018
ODP	kg CFC-11 eq	2.2E-07	1.4E-07
HTP	kg 1,4-DB eq	0.59	0.86
FAEP	kg 1,4-DB eq	0.32	0.074
MAEP	kg 1,4-DB eq	352	526
TEP	kg 1,4-DB eq	0.0069	0.012
POCP	kg C2H4	0.0010	5.2E-04

Energy: cumulative energy demand, *GWP* global warming potential; *ADP* abiotic depletion; *AP* acidification potential; *EP* eutrophication potential; *ODP* ozone depletion potential; *HTP* human toxicity potential; *FAEP* freshwater aquatic ecotoxicity potential; *MAEP* marine aquatic ecotoxicity potential; *TEP* terrestrial ecotoxicity potential; *POCP* photochemical ozone creation potential

The main contribution to the environmental impact clearly came from production of the e-book reader. To some extent, the waste treatment of the obsolete device led to avoided impact, through recycling of metals and energy recovery from waste incineration. Other phases of the life cycle only contributed a small share of the total impact.

The main contributors to the potential environmental impact categories were the integrated circuits (energy, abiotic depletion, global warming, eutrophication, human toxicity, freshwater aquatic toxicity, marine aquatic toxicity, terrestrial toxicity), the resistors (acidification, terrestrial toxicity, photochemical ozone creation), the capacitors (acidification, photochemical ozone creation) and the battery (ozone layer depletion). For the acidification and photochemical ozone creation, palladium was a main source of the impact. Use of gold was a major reason for

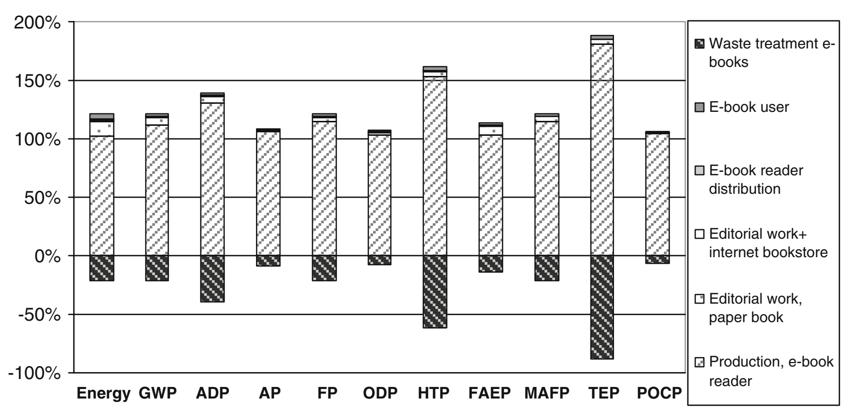

Fig. 1 Contribution of the main life cycle phases of an e-book read on an e-book reader. Impact category abbreviations are listed in Table 1

the terrestrial ecotoxicity impact and recycling of gold reduced the total impact. Disposal of waste from palladium refining and from wafer production were the main reasons for fresh water aquatic toxicity and marine aquatic toxicity. The latter was also the main reason for eutrophication. For human toxicity, the production of aluminium and copper were main contributors, and recycling of aluminium decreased the total impact.

Use of electricity in production made a considerable contribution to several of the impact categories (abiotic depletion, global warming, marine aquatic toxicity, terrestrial toxicity).

4.2 e-book compared with paper book

Figure 2 and Table 1 compare the potential environmental impact related to the e-book life cycle with that of a paper book life cycle. The assessment of the paper book is described in Borggren et al. (2011) and Borggren and Moberg (2009). With the total reading in the base scenario of 17,000 pages (48 books) per e-book reader, the e-book was preferable to the hardback paper book studied here in terms of resources used, global warming, energy, eutrophication, human toxicity, marine aquatic ecotoxicity and terrestrial ecotoxicity. However, the paper book was preferable in terms of acidification, ozone depletion, freshwater aquatic ecotoxicity and photochemical ozone creation. The potential acidification impact of production of the e-book reader was mainly due to the palladium used in many of the electronic parts of the e-book reader. The data available in SimaPro are for palladium production with no filter for sulphur dioxide emissions. The cumulative energy demand of the paper book was considerably higher than of the e-book, mainly due to the energy contained in the biomass from the forest, but, e.g. energy used in the bookshop was also substantial.

The environmental impact of an e-book was dependent on the total use of the e-book reader. With few books read during the life of the electronic device, paper books were preferable from an environmental perspective. Comparing the environmental performance of the two alternative books, the breakeven point for global warming potential was different for different impact categories (Fig. 3). For several impact categories (climate change, abiotic depletion, eutrophication, human toxicity, marine aquatic ecotoxicity and terrestrial ecotoxicity), the break even is in this study around 30 books. Only when a larger amount of books, as defined here, are assumed to be read could e-books be justified from the perspective of these impact categories. However, if the paper books were assumed to be read twice (halving the environmental impact per book read) the break even is around 60–70 books. For the other impact categories studied, the break even is higher (see Fig. 3). For example, regarding acidification about 200 books, as defined here, would need to be read in order to justify e-books on the e-book reader. For the cumulative energy demand the lowest break even was shown, with less than 20 books.

5 Discussion

Dematerialisation through replacement of products with virtual goods is seen as one possible contribution of ICT towards environmental sustainability. In the case of printed and electronic media, several studies have shown environmental benefits of electronic versions, but also disadvantages. Dematerialisation has a sensory aspect, as less material and less weight can easily give a feeling of implicitly less environmental impact. With the underlying assumptions of the comparison made here, 48 paper books of 360 pages each would be replaced by e-books read on one e-book reader. In this case, the weight of the end product would decrease by a factor of 60. However, the results of this study show that there is considerable environmental impact related to the production of the electronic device that needs to be taken into account. The

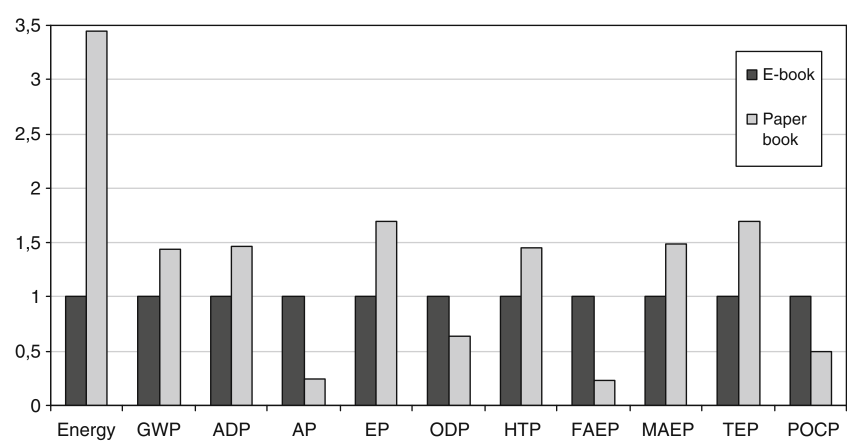

Fig. 2 Comparison of an e-book and a paper book distributed via a traditional bookshop. Impact category abbreviations are listed in Table 1

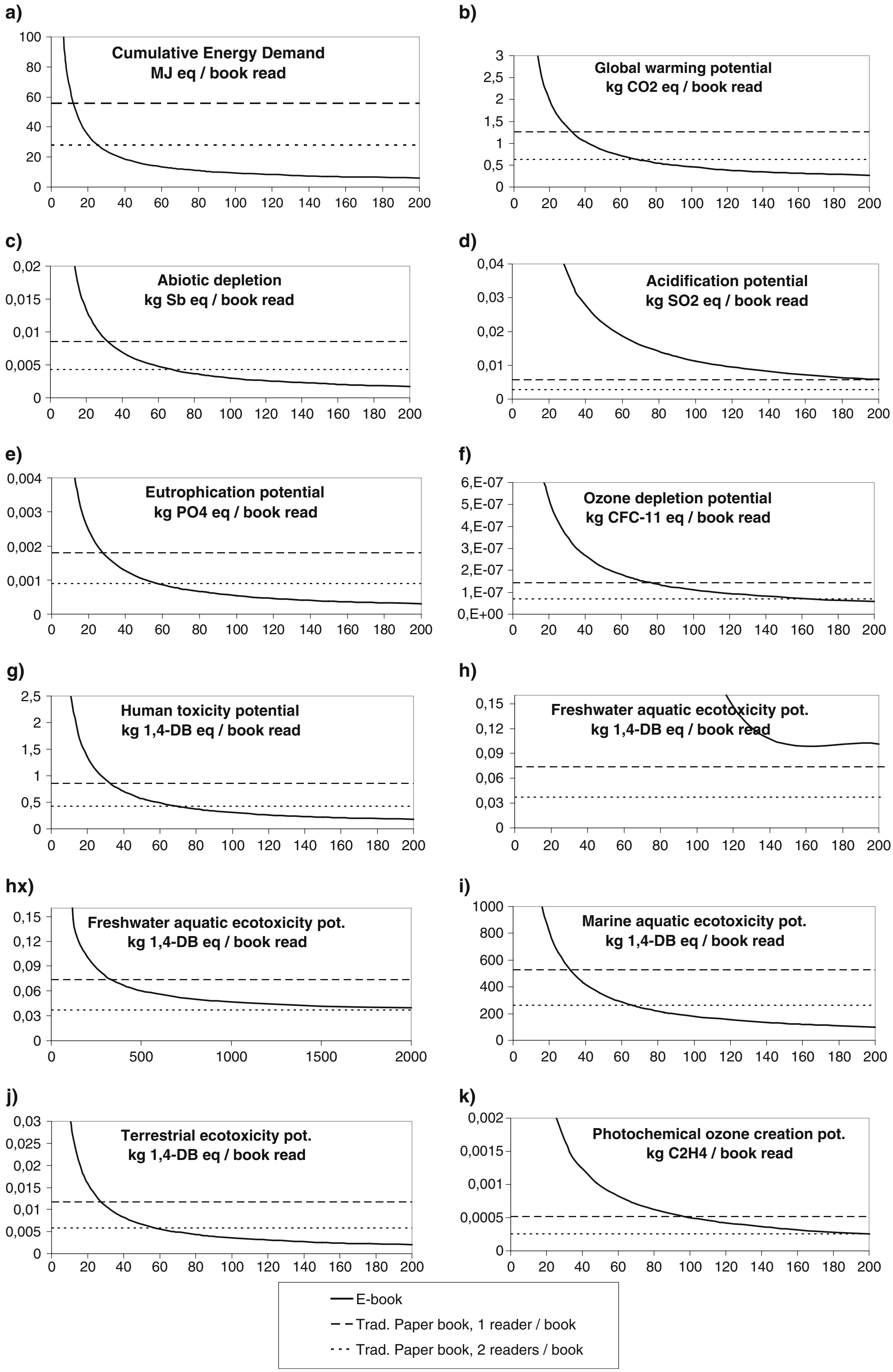
a)
Cumulative Energy Demand
MJ eq / book read
b)
Global warming potential
kg CO2 eq / book read
c)
Abiotic depletion
kg Sb eq / book read
d)
Acidification potential
kg SO2 eq / book read
e)
Eutrophication potential
kg PO4 eq / book read
f)
Ozone depletion potential
kg CFC-11 eq / book read
g)
Human toxicity potential
kg 1,4-DB eq / book read
h)
Freshwater aquatic ecotoxicity pot.
kg 1,4-DB eq / book read
hx)
Freshwater aquatic ecotoxicity pot.
kg 1,4-DB eq / book read
i)
Marine aquatic ecotoxicity pot.
kg 1,4-DB eq / book read
j)
Terrestrial ecotoxicity pot.
kg 1,4-DB eq / book read
k)
Photochemical ozone creation pot.
kg C2H4 / book read
E-book
Trad. Paper book, 1 reader / book
Trad. Paper book, 2 readers / book

Fig. 3 Potential impacts per e-book as a function of total amount of e-books read on an e-book reader. The potential impact of a paper book, with one and two readers per book respectively, is also illustrated (Borggren et al. 2011). The x-axis shows total number of books read and the y-axis the potential environmental impact per book read. Note that in all figures the maximum value on the x-axis is 200 books except in figure **hx**) where the number is 2000 as the scale was too small to show the break-even point in figure **h**)

comparison between reading e-books on dedicated readers and paper books showed that there are advantages and disadvantages with both product systems from an environmental perspective. The results indicate that in order to be beneficial from an environmental perspective, reading an e-book on an e-book reader needs to be linked to high total usage of the e-book reader. This usage could also be for other purposes, for example newspapers, magazines. Furthermore, the electronic reading would need to replace printed media in practice or additional environmental impact would be resulting instead of a potential decrease. The number of books, or other media, read on a specific e-book reader will be dependent on the lifetime of the device, which will be defined both by the technical lifetime and the time during which it is actually used and not replaced by a newer version, etc. In addition, the habits of the user concerning frequency of reading will decide the total usage of the e-book reader.

Borggren et al. (2011) showed that different preconditions can lower the environmental impact of paper books, which would lead to higher requirements on the use of the e-book reader to justify it from an environmental perspective. Lower environmental impact per paper book read can be predicted for, e.g. paperback books, books with fewer pages and books with more readers. This is relevant for the comparison to e-books as it can be argued that the paper books substituted by e-books may rather be paperback books. Studies of user practices would need to be made to get further information on whether users actually substitute paper books and which kind.

As indicated in Borggren et al. (2011), paper books bought via the internet and delivered by postal services have a lower impact than the same book bought in the bookshop by a person using a car to get there. The environmental impact of paper books can also differ depending on the location and technology of the pulp and paper mill, as well as the printing office.

Other studies comparing electronic and printed media and showing that electronic media are preferable to printed (Kozak 2003; Moberg et al. 2007, 2010; Toffel and Horvarth 2004) may have reached this conclusion due to the use of non-comprehensive data on production, but also due to an assumption of frequent use. Different media also have different use patterns, e.g. reading a newspaper seldom consists of reading all the text printed, as is the case for a novel. Hischier and Reichart (2003) showed that different ways of assessing media, in their case news, using different functional units gave different results. Key issues were shown to be the reading time for electronic media and the amount of paper needed for the printed media; in addition, the electricity mix used was relevant for the electronic media environmental impact (Hischier and Reichart, 2003). Moberg et al. (2007, 2010) compared a printed newspaper with a newspaper read on an e-reader device and, with the assumptions made in that study, the latter was preferable from an environmental perspective. The data available on production and waste management of the device were limited, e.g. for the printed wiring boards, the component mix was taken from the electronic component configuration of a personal computer motherboard. The GWP of the e-reader device assessed in Moberg et al. (2007, 2010) was roughly 20 kg CO_2-eqv/device, which can be compared with 40 kg CO_2-eqv/device in this study. For most other impact categories, the difference was larger with the values in Moberg et al. (2007, 2010) being lower. The data used in the present study were also uncertain, as they were based on connecting components in the dismantled device to the available data on electronic components in Ecoinvent 2.0. No data were available for the e-ink screen or on energy use for assembling the e-book reader. Inclusion of these factors would increase the impact, but the extent of the increase cannot be estimated. Production of the e-ink screen may be an energy-intensive process, which could be significant for the resulting environmental impact.

For comparison, it can be mentioned that the production of a laptop computer (Hischier et al. 2007) gives rise to roughly 250 kg CO_2-eqv and the production of a mobile phone 13 kg CO_2-eqv (Bergelin 2008). Reading e-books on such devices that are also used for other purposes to a large extent would lead to a smaller share of the total impact of production being allocated to the e-book. However, the energy in the use phase needs to be kept at low levels to get a low total impact.

Information on the waste management of obsolete e-book readers is still uncertain. Knowledge on how e-book readers are disposed of is lacking and the general information on electronic waste is limited. A Swedish study on small electronic waste in households (Avfall Sverige 2008) reported that many mobile phones tend not to enter the recycling system, probably because they are still kept in the home but not used. Hardly any mobile phones have been detected in analyses of household waste, but the number of discarded mobile phones that leave Sweden and are disposed of in other countries is not known (Avfall Sverige 2008). Based on this lack of knowledge, our assumption on disposal of e-book readers was that only 75% of the e-book readers reached the recycling system. Data on material recycling processes were taken from Ecoinvent 2.0, and there were data gaps and uncertainties

regarding the exchange for virgin material, etc. The waste devices that did not reach the recycling system and the parts that were not suitable for incineration or material recovery (mainly the screen) were not included in the study, since there were no data available to estimate the environmental impact. Overall, the environmental impact of the disposal phase was probably underestimated here, although a higher degree of devices reaching the recycling system would lead to more material recovery.

Other studies on books have focused on scholarly books (Enroth 2009; Kozak 2003) studies differed in geographical scope and the actual products studied, as well as in terms of results. Considering CO_2-emissions, Enroth (2009) found a printed book to have less impact per kg than Kozak (2003), with each printed book compared with 400 h of reading the electronic version on a computer (each book used by five pupils). Kozak (2003), on the other hand, assumed only one user for each printed book and compared this with 32 h of reading on an e-reader device with LCD screen. These two very diverging studies further emphasise the wide range of possibilities when comparing printed and electronic media with 'the same' function.

When comparing e-books with paper books, it would be interesting to consider paperback books as well. For a rough indication, the paperback book would require roughly half the weight of paper of the hardback book, and thus, each paper book would probably have a lower environmental impact if produced in paperback rather than hardback and if all other processes and assumptions were the same. Another difference when comparing e-books and paper books, which was not covered in the study, is the potential decrease in the need for storage in the home, which in a broader perspective, could facilitate smaller living space. Accounting for the energy required for heating, the space occupied by each book for several years would lead to additional environmental impact of the paper book (Borggren et al. 2011), and provide another potential benefit of replacing paper books with e-books. On the other hand, storing books also means storing carbon. The amount of carbon stored in a book may be significant compared with the emissions of carbon during the life cycle of that a book.

This study was a screening LCA and all impact categories of relevance were not equally well covered. As for many other LCA studies (Finnveden 2000), the toxic impact categories were plagued with data gaps and impacts from land use were not covered. The latter are of relevance for both paper books (forestry) and e-books (mining activities).

6 Conclusions

The main contribution to the total environmental impact of the e-book life cycle is from the production, and to some extent, the disposal of the e-book reader. There are uncertainties concerning the data, especially for the disposal. In addition, there are several substances and emissions related to both the production and waste management of the e-book reader that may have toxicological implications, and it should be noted that the uncertainties are large for the toxicological impact categories in general. There are knowledge gaps, making it difficult to characterise toxicological impacts, and there are data gaps concerning toxicological emissions in the data inventories.

The results indicate that there is no single answer as to which book is better from an environmental perspective. The environmental benefit of e-books compared with paper books depends on parameters that vary for each book and user. To improve the e-book results, an e-book reader should be used by frequent readers, and if possible, for different purposes such as reading books, newspapers, journals and other documents, thus lowering the impact per functional unit. The lifetime of the device should be prolonged as far as possible, and when no longer in use, the device should be disposed of in a proper way, making material recycling possible.

7 Recommendations and perspectives

Media consumption is increasing, especially of electronic media. This study indicates the need for more studies on a macro level in order to assess the magnitude of the environmental impacts of changing media practices, to identify new media practice that could have the potential to produce environmentally significant advantages and to determine the major risks for negative environmental impacts. Studying new media and communication solutions from an environmental perspective demands a life cycle perspective and even if the function of a new solution is often not exactly comparable with the old solution comparisons will indicate the potential differences between the two. More detailed studies on the management of electronic waste are needed. The assessment of toxicological emissions needs to be further developed to avoid the shift of environmental problems towards these impact categories. The assessment of complex products, such as electronic devices, will become more comprehensive as databases develop and include new inventory data, which may lead to further increases in the environmental impact identified.

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